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RESEARCH ARTICLE

Length-based estimates of growth parameters and mortality rates of fish populations from a coastal zone in the Southeastern Brazil

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ABSTRACT. Small-scale fisheries in Brazil contribute to a significant share of total fish production, accessing a large variety of species. Life history parameters from these resources are important for their management and conservation, based on primary data. The objective of this article is to generate growth parameters and mortality rates of ten fish populations from a coastal zone in Southeastern Brazil. Monthly samples were taken between January 2011 and November 2014 from landings of the beach-seine fishery in an area adjacent to the entrance of the Guanabara Bay. All fishes were measured (total length) and weighed. The length-weight relationships (LWR) were estimated by linear regression analysis on log-transformed data of the equation: $W = aL^b$. The Von Bertalanffy Growth Function (VBGF) was fitted to size-at-age data to obtain growth parameters (K, L_∞). The length-converted catch curve was used for estimating the instantaneous total mortality (Z). Taylor's equations provided an independent estimate of the natural mortality (M) and longevity. The difference between Z and M derived Fishing mortality (F). A total of 2,938 individuals from ten fish species were used to determine the length-weight relationships. *Harengula clupeola* (Cuvier, 1829) has a new maximum length record for the FishBase LWR database. *Sardinella brasiliensis* (Steindachner, 1879) presented the smallest and largest size recorded for LWR observed in the literature and FishBase database. *Upeneus parvus* showed the greatest total length, while *Trichiurus lepturus* Linnaeus, 1758, *Orthopristis ruber* (Cuvier, 1830) and *Dactylopterus volitans* (Linnaeus, 1758) presented the smallest sizes for LWR in FishBase. The other species showed parameters within the expected values for each group. The performance index combining information from K and L_∞ presented values between 2.32 and 3.76 and were considered appropriate for the populations evaluated. Fishing was the primary source of mortality for *Caranx crysos* (Mitchill, 1815), *Eucinostomus argenteus* Baird & Girard, 1855, *S. brasiliensis* and *U. parvus*, and less important for *Cynoscion jamaicensis* (Vaillant & Bocourt, 1883), *D. volitans*, *O. ruber*, *Selene setapinnis* (Mitchill, 1815), *T. lepturus* and *H. clupeola*. The parameters generated may be used for the management and conservation of the species' stocks.

KEY WORDS. Ichthyofauna, length-weight relationships, life history, shallow waters, small-scale fisheries.

INTRODUCTION

Direct readings of hard structures (e.g., otoliths, spines, vertebrae) to estimate the age of fish, or indirect estimates based on length distribution data over time are traditional methods to determine growth parameters of fish populations (Gayanilo et al. 2002, Panfili et al. 2002). Indirect stock assessment tools are relatively more useful in tropical and sub-tropical waters since hard structures in these relatively warm waters, where seasonal differences are subtle, often present unclear band marks (Sparre

and Venema 1992, Panhwar and Liu 2013). The development of the length-based stock assessment methodologies and relative growth models (Huxley 1993), simplified the investigation of population dynamics of fish stocks in tropical waters (Froese and Binohlan 2000). These methods were applied in recent decades (Sparre and Venema 1992, Castro et al. 2002, Velasco et al. 2007, Panhwar and Liu 2013) to tests life-history hypothesis (e.g. Stergiou 2000) and provided empirical estimations of relevant biological and fishery parameters such as length at first maturity and longevity (Froese and Binohlan 2000). Thus, stock assessment becomes a basic management approach to help the understanding of growth (relative to the individual and the population) and death of fish (Jennings et al. 2001). It also contributes to making predictions about the exploitation of fish populations, which may help for the selection of alternative management choices (Costa and Araújo 2003, Froese 2006, Garcia and Duarte 2006, Costa et al. 2014, Sá-Oliveira et al. 2015).

The lack of growth and mortality estimates is widespread for coastal marine fish populations. These are essential parameters for modeling population dynamics of fish stocks and ecosystems (Sparre and Venema 1992). They contain information on the biology and ecology of the population under study, indicating its renewal and productivity, since species with higher rates of natural mortality also have higher rates of growth and reproduction, generating more biomass per unit of time.

In Brazil, small-scale fisheries contribute a significant share of total fish production, accessing a large variety of species. These fisheries often exploit coastal fishery resources, as the fleet is mostly limited by size and technology (Chuenpagdee and Pauly 2008). A small-scale fishery operating in the coastal zone of Itaipu has a key socioeconomic role for local fishers and the communities in which they live. More than 90 species are captured in different fishing gears, leading to an estimated annual production of 108 tons (CPUE = 38.8 kg*trip^{-1}) (Loto et al. 2018). Beach seining is the traditional fishery, practiced for over 100 years, and responsible for half of the total production volume. Gear selectivity was low capturing several species and individuals of all sizes. Currently, the traditional fishing grounds where most of the local fishery concentrates were declared a Territorial Use Rights for Fisheries (TURF), a type of marine protected area (Afflerbach et al. 2014), the Itaipu Marine Extractive Reserve – Itaipu RESEX (Freitas et al. 2017). It is an area of 3,943.28 hectares in which fishers, government, and local civil society representatives define management strategies for the sustainable use of fisheries and natural resources (Brasil 2011). Several studies in the area focused on the anthropological aspects of fishers organization and traditional knowledge (Kant de Lima and Pereira 1997), fisheries production (Tubino et al. 2007), species list and connectivity between nursery habitats and fishing grounds (Monteiro-Neto et al. 2008) and changes in the fishery over time (Tubino et al. 2014, Loto et al. 2018). Nevertheless, few attempts have addressed the development of monitoring programs to collect life history information of the predominant stocks exploited by this small-scale fishery. To overcome this gap, we used length-based stock assessment tools for estimating growth parameters and mortality rates of ten selected fish populations exploited within a TURF type reserve in a Southeastern Brazil coastal zone.

MATERIAL AND METHODS

The Itaipu coastal zone (22°53’14” S, 43°04’00” W) covers an intensive small-scale (artisanal) fishery established in the area since the 18th century. Today, nearly 110 fishermen realize their catches in areas down to 50 m deep (Loto et al. 2018). The area is located to the west of the mouth of Guanabara Bay and forms a semi-sheltered cove protected by three coastal islands (Fig. 1). The coastal water mass is a mix of Guanabara Bay waters, contributions from the Itaipu-Piratininga lagoons, and coastal oceanic waters, seasonally influenced by weak upwelling of the South Atlantic Central Water, following the general pattern for the South Atlantic Bight (Castro-Filho et al. 1987).

We monitored the artisanal beach-seine fishery landings in Itaipu on a monthly basis from January 2001 to November 2004, recording catch composition, abundance and fish size structures. Beach-seine operations were considered as boat trips, and teams of two to three observers at the landing site monitored all trips during the sampling day. Once a month one beach-seine operation was fully monitored to record the whole fishing process, including the sorting and marketing of the catch. All collected specimens (license SISBIO #15787-1) were placed in plastic bags, labeled and stored on ice during transport to the laboratory where they were screened and identified at the lowest taxonomic level (e.g. Figueiredo and Menezes 2000, Figueiredo and Menezes 1980). All fishes were measured for total length (±1 mm precision) and weighed with an electronic scale (±0.01 g precision). Vouchers of reference specimens collected in this study are available in the icthyological collection of Laboratório de Biologia do Nécton e Ecologia Pesqueira (LNEP-UFF). The fish size structure data were grouped seasonally, due to the standard fishing effort (the same net of 250 m long, 15 m high, 45 cm mesh) within the same fishing area. The entire fishing operation involves between ten and 15 fishers and a large dugout wooden canoe up to nine meters in length. The seasonal groups followed approximately the conventional southern hemisphere four seasons definition: Summer – January to March; Fall – April to June; Winter – July to September; and Spring – October to December. The equation used to calculate the LWRs was:

$$W = aL^b$$

where W is the total weight of fishes (g), a is the coefficient related to body shape, L is the total length (cm), and b is an exponent related to changes in body shape (Le Cren 1951, Froese 2006). Statistica 7.0 software (Statsoft 2005) was used to adjust the model; the linear regression

$$\log(W) = \log(a) + b\log(L)$$

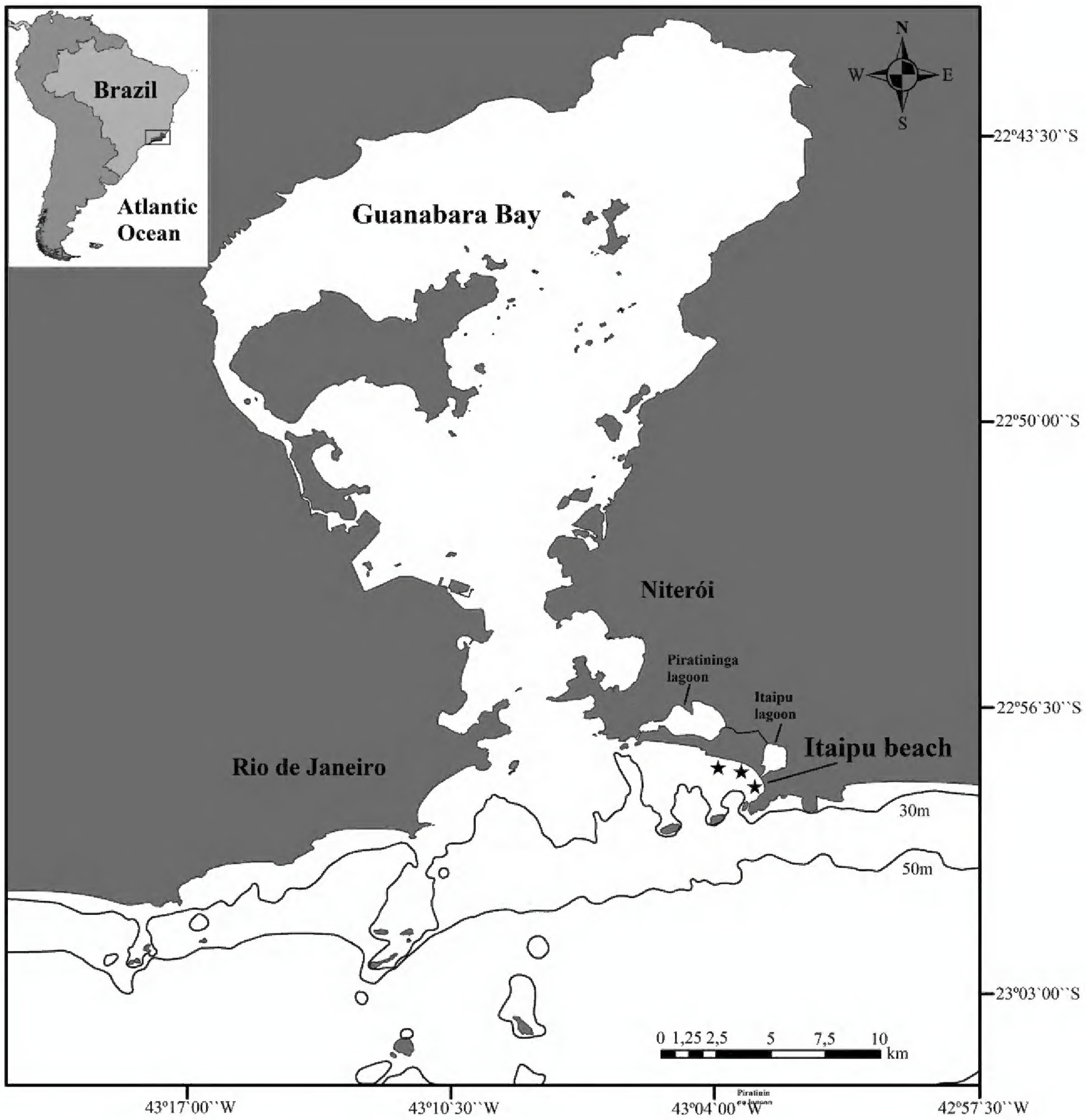

Figure 1. Geographical location of Itaipu coastal zone of Rio de Janeiro, Brazil, showing fishing areas (stars).

estimated parameters '*a*' and '*b*'; extreme outlier values were excluded from the analyses. Additionally, 95% confidence limits (CL) of '*a*' and '*b*' were estimated. The r-squared (R^2) Pearson coefficient provided an estimate of model fit.

Growth rates were calculated using the seasonal von Bertalanffy's equation, where L_t is the length of the fish (cm) at age *t* (year), L_∞ is the asymptotic total length (cm), *k* is the constant growth rate (year^{-1}), and t_0 (year) is the nominal age at which fish length is considered to be zero. The *k* constant was calculated in the FISAT II software (FAO-ICLARM 1996, Gayanilo and Pauly 1997) using the ELEFAN I routine (Pauly and David 1981), which uses the modal displacement of length classes time series to provide an index of growth rates for different age classes. Additionally, the parameters *C* (seasonal oscillation amplitude – Castro et al. 2002) and *Wp* (winter point – the time of the year of slowest growth – Gomieiro et al. 2007) were also determined.

The best growth curve was fitted, based on the "Rn value" a non-parametric goodness of fit index (Gayanilo et al. 2002). For the calculation of theoretical age at length zero (t_0) we used the Pauly's empirical formula (Pauly 1979):

$$\log(-t_0) = \log - 0.3922 - 0.2752\, L_\infty - 1.038 \log k$$

The values of L_∞ and L_{50} (estimated from L_∞) were found using the length of the largest individual (L_{max}) and Froese and Binohlan's (2000) equations:

$$\log(L_\infty) = 0.044 + 0.9841 \times \log(L_{max})$$

and

$$\log(L_{50}) = 0.8979 \times \log(L_\infty) - 0.0782$$

To standardize the data, t_0 was considered to be zero for all populations. The length-converted catch curve method (Gayanilo et al. 2002) estimated the instantaneous total mortality (*Z*), and Taylor's equation (Taylor 1958) natural mortality (*M*):

$$M = 2.996/A\ 0.95\%$$

Fishing mortality (*F*) was derived from the difference between *Z* and *M*, and the exploitation ratio (*E*) from fishing mortality/total mortality. Longevity (*A* 0.95%), defined as the time the individual takes to reach 95% of the asymptotic length, was estimated based on the formula proposed by Taylor (1960):

$$t_{max} = t_0 + 2.996/k$$

Growth performance indexes (Munro and Pauly 1983) were calculated as:

$$\theta = \log(k) + 2 \times \log(L_\infty)$$

The indices obtained were compared with values from other stocks of the same species available on FishBase (http://www.fishbase.org) or the literature.

RESULTS

A total of 2,938 specimens representing ten different fish species (eight families) were used to determine the length-weight relationships (LWR). A new maximum length was recorded for *Harengula clupeola* (Cuvier, 1829) (22.5 cm TL). The data set does not provide first records for the other species in the FishBase database, but present larger and smaller size amplitudes than those previously reported for Brazil and the FishBase. *Upeneus parvus* Poey, 1852 presented a highest total length; *Sardinella brasiliensis* (Steindachner, 1879) presented the lowest and highest TL while *Trichiurus lepturus* Linnaeus, 1758, *Orthopristis ruber* (Cuvier, 1830) and *Dactylopterus volitans* (Linnaeus, 1758) presented the lowest TL values. Table 1 provides the results of the LWR analyses along with the descriptive statistics. In the present study, the coefficients of determination (R^2) ranged from 0.95 to 0.99.

Population estimates obtained from seasonally adjusted length frequency data were achieved for most important fish species captured by the beach seine fishery. Table 2 summarizes the growth parameters, mortality rates and longevity estimated from our data set. The largest individuals of each species (L_{max}; cm) were used in the analysis to minimize the overestimation of L_∞ and K, and growth curves for juveniles showed a steep increase tapering off approaching L_∞.

In general, our θ values are within the range of θ values from the literature to all species evaluated, except for *U. parvus* from which growth parameters were inexistent for the coast of Brazil. Fishing was the most important source of mortality for *Caranx crysos* (Mitchill, 1815), *Eucinostomus argenteus* Baird & Girard, 1855, *S. brasiliensis* and *U. parvus*, and less important for *Cynoscion jamaicensis* (Vaillant & Bocourt, 1883), *D. volitans*, *O. ruber*, *Selene setapinnis* (Mitchill, 1815), *T. lepturus* and *H. clupeola*.

Longevity estimates related to the growth constant (k) are within the expected values for all species evaluated, corresponding to the age at which 95% of the population would die from natural causes.

Table 1. Sample size (n), ranges of total length (LT) and weight (TW) of fish species. Values and confidence limits (CL) of *a* and *b*, coefficients of determination (R^2) and type of growth (ALO+, positive allometric; ALO-, negative allometric and ISO, isometric).

Family	Scientific name	n	TL (min – max)	TW (min – max)	*a*	-*a* CL	*a* CL	*b*	-*b* CL	*b* CL	R^2	t_{calc} (α 0.05)	Type growth
Clupeidae	*Harengula clupeola*	430	3.2–22.5	1.0–109.0	0.007	0.006	0.007	3.22	3.16	3.28	0.96	7.10	ALO+
	Sardinella brasiliensis	310	3.2–25.5	0.2–119.0	0.005	0.004	0.006	3.13	3.06	3.19	0.97	3.85	ALO+
Dactylopteridae	*Dactylopterus volitans*	246	1.5–31.9	2.0–358.0	0.021	0.017	0.025	2.76	2.69	2.84	0.95	-6.19	ALO-
Carangidade	*Caranx crysos*	162	10.2–33.5	16.0–473.0	0.008	0.005	0.011	3.14	3.03	3.25	0.95	2.48	ALO+
	Selene setapinnis	318	3.5–35.0	1.0–463.0	0.015	0.014	0.016	2.94	2.91	2.97	0.99	-4.16	ALO-
Gerreidae	*Eucinostomus argenteus*	475	4.6–21.0	1.0–110.0	0.009	0.008	0.011	3.14	3.08	3.20	0.96	4.50	ALO+
Haemulidae	*Orthopristis ruber*	287	3.5–27.0	0.9–250.0	0.015	0.012	0.016	3.01	2.95	3.08	0.97	0.44	ALO+
Scianidae	*Cynoscion jamaicensis*	135	5.4–27.8	5.0–300.0	0.010	0.007	0.014	3.06	2.96	3.17	0.96	1.19	ISO
Mullidae	*Upeneus parvus*	230	5.5–23.0	1.0–180.0	0.004	0.003	0.005	3.41	3.31	3.51	0.95	7.96	ALO+
Trichiuridae	*Trichiurus lepturus*	345	4.2–138.0	3.0–2,000.0	0.001	0.001	0.001	3.02	2.95	3.09	0.96	0.50	ISO

Table 2. Values of constant growth rate (k; $year^{-1}$), asymptotic total length (L_∞; cm), nominal age at which fish length is considered zero (t_0; year), C (seasonal oscillation amplitude; C°), Wp (winter point); growth performance index (θ; Phi); instantaneous total mortality (Z), natural mortality (M), fishing mortality (F), exploitation ratio (E), length of first sexual maturity (L_{50}), proportion of individuals below the length of first sexual maturity ($n < L_{50}$;%) and longevity ($A_{0.95\%}$; years) by small scale fisheries in Itaipu costal zone.

Family	Scientific name	K ($year^{-1}$)	L∞	t_0	C	Wp	θ (Phi)	Rn value	Z	M	F	E	L_{50}	$n < L_{50}$ (%)	$A_{0.95\%}$
Clupeidae	*Harengula clupeola*	0.43	23.68	-0.41	0.25	0.91	2.38	0.678	1.11	0.97	0.14	0.13	14.3	84.0	6.56
	Sardinella brasiliensis	0.26	23.68	-0.80	0.25	0.67	2.16	0.519	1.64	0.70	0.94	0.57	15.8	85.5	10.73
Dactylopteridae	*Dactylopterus volitans*	0.30	33.58	-0.57	0.25	0.91	2.53	0.403	0.95	0.70	0.25	0.26	19.5	72.4	9.42
Carangidade	*Caranx crysos*	0.65	35.26	-0.21	0.25	0.65	2.91	0.965	2.94	1.14	1.80	0.61	20.4	7.4	4.40
	Selene setapinnis	0.49	36.84	-0.30	0.25	0.10	2.82	0.417	1.22	0.94	0.28	0.23	21.2	76.7	5.81
Gerreidae	*Eucinostomus argenteus*	0.47	22.11	-0.38	0.25	0.66	2.36	0.393	2.68	1.06	1.62	0.60	13.5	33.9	6.00
Haemulidae	*Orthopristis ruber*	0.38	28.42	-0.44	0.25	0.91	2.49	0.753	1.09	0.86	0.23	0.21	16.9	86.1	7.44
Scianidae	*Cynoscion jamaicensis*	0.36	29.20	-0.48	0.25	0.83	2.49	0.586	1.02	0.82	0.20	0.20	17.3	2.2	7.84
Mullidae	*Upeneus parvus*	0.36	24.21	-0.51	0.25	0.41	2.32	0.937	1.83	0.87	0.97	0.53	14.6	87.0	7.81
Trichiuridae	*Trichiurus lepturus*	0.64	145.26	-0.10	0.25	0.49	4.13	0.803	0.96	0.77	0.19	0.20	71.1	65.5	4.58

DISCUSSION

This study was conducted to determine some of the key management parameters of growth, mortalities, exploitation rate, longevity and size of the first maturity for fish species caught by the beach-seine artisanal fishery conducted within the Itaipu RESEX, a TURF type protected area. Estimates of population parameters are essential for understanding the biological characteristics of fish species, in particular, those targeted by commercial fisheries (García and Duarte 2006, Freitas et al. 2014). The present data set was collected over a constant time interval, with fishing operations conducted with similar effort patterns within the same fishing area. However, as expected, the data set does not cover the whole lifespan of the selected fish populations, including representative samples of fry, juveniles, and adults. In fact, such results are seldom achieved even when using the most selective fishing gears (Panhwar and Liu 2013). Therefore, we assumed that the pooled capture data for the whole period represents the average stock composition of each species under consideration.

The relative growth parameters reported are within the range documented in the literature for all ten species. These are widely distributed with a widespread occurrence on the South-southeastern coast of Brazil (Vianna et al. 2004, Haimovici and Velasco 2000, Costa et al. 2014, Franco et al. 2014). Genetic, environmental (resource availability), and population factors (density) may influence length parameters (TL_{max} and L_{∞}). On the other hand, growth rates (k) are determined genetically and physiologically (TL_{max} and L_{∞}) (Beverton and Holt 1957, Sparre and Venema 1992). Thus, small variations in the distinction between the measured and predicted values or those presented here vs. literature might be influenced by several factors, including the number of sampled specimens, gonad maturity, sex, and growth phase (Froese 2006). The variations in b values, compared with the available records, may be influenced by habitat type (Ruiz-Campos et al. 2010), food availability, condition factor (Froese et al. 2011), formalin effects on specimens (Teixeira de Mello et al. 2011) or other uncontrolled factors such as seasons or extreme environments (Costa et al. 2014, Wang et al. 2016). Therefore, the relative growth parameters allow determining whether somatic growth is isometric or allometric (Araújo and Vicentini 2001). Furthermore, they may be valuable tools to estimate (i) fish condition (Santos et al. 2002); (ii) biomass from length observations (Morato et al. 2001); (iii) weight-at-age (Santos et al. 2002) and convert growth-in-length to growth-in-weight equations (Gonçalves et al. 1997, Stergiou and Moutopoulos 2001); and (iv) may still be used for between-region comparisons of species life histories (Filiz and Bilge 2004, Gökçe et al. 2010).

Beach seining is one of the oldest and most traditional fishing methods employed in Brazil, practiced on dissipative sandy beaches with a gentle slope and vast areas to extend the net (Kant de Lima and Pereira 1997, Fagundes et al. 2007). This non-selective gear captured seasonal target species in the Itaipu RESEX, providing age-at-length data of combined juveniles and adults, which contributed for less biased estimates to describe local fish populations. Furthermore, it provided insights into the fisheries potential within the fishing area, that is, the real use of several population strata of different species.

The population parameters recorded in the present study suggests the existence of a fish fauna adapted to various local environmental constraints (spatial, temporal, or both), reflecting the habitat partitioning as they undergo biological development. Some of these species (e.g. *C. crysos*, *E. argenteus*, *H. clupeola*, and *S. brasiliensis*) are true "r" strategists, showing opportunistic life history strategies exploring empty ecological niches, spawning large batches of eggs without parental care and subjected to very high mortality rates during the first weeks of life. Individuals usually have a short lifespan and habitat carrying capacity is not a restrictive factor. This assemblage forms the bottom of the food chain.

On the other hand, species such *C. jamaicensis*, *D. volitans*, *O. ruber*, *S. setapinnis*, and *T. lepturus*, showed the "K" strategist life history strategy. Individuals are reaching larger sizes at a slow growth with low mortality rates. There is a greater parental care investment in the brood with offsprings showing higher survival probability in well busy niches. Such species are suited for life in resilient environments (Luiz et al. 2005), within sustainable limits of the habitat carrying capacity, and represent the top of the food chain. Groups "r" and "K" strategists may be recognized within the species analyzed, characterizing the multiple life history strategies observed in highly productive areas such as the Itaipu RESEX (Monteiro-Neto et al. 2008, Tubino et al. 2007, Morasche et al. 2010).

Natural mortality rate M and longevity showed dimensional reciprocity, but their precise relationship is complex and depends on both natural factors (e.g. changes in M with age due to senescence) and technical aspects such as sampling (e.g. the type of fishing net) and age-determination (Beverton 1992). Both, mortality and longevity obtained in the present study were calculated with parameters derived from the von Bertalanffy equation. These included t_0, k, and the value of 2.996 obtained from the transformation: LN (1–p) for $P = 0.95$. This value represents the proportion of TL_{max} to L_{∞}, both obtained from the VBGF. Calculating M from the expected maximum age indicated that populations with most longevous individuals often present a lower rate of M. In fact, M is one of the parameters for which a good estimate is harder to obtain and is often the greatest source of uncertainty in inventory valuation (Pauly 1980, Vetter 1988). On the other hand, this is a necessary value for most stock dynamic models.

Using M and Z estimates, the current fishing mortality (F) was calculated for each species. Comparing the estimated values for M and F, it is possible to conclude that the fishery was the most important source of mortality ($F > M$) for *C. crysos*, *E. argenteus*, *H. clupeola* and *U. parvus* stocks. Fishing and natural

mortality are practically the same for *C. jamaicensis*, whereas for other species fishing is less important than the other sources of mortality ($F < M$). Thus, from these results, it is plausible to assume that the stocks showing the "r" strategist behavior were under greater fishing pressure than the other species in question. Also, the levels of exploration (**E**) in the studied populations corroborate our hypothesis related to *F*. In fact, Gulland (1971) and Patterson (1992) suggested optimal **E** values between 0.5 and 0.4 respectively. Our lower **E** values occurred in those species under less pressure of the beach seine fishery. However, regardless of fishery control, there is the need for an independent survey of species populations to support this hypothesis further. The interpretation provided represents first insights into the current status of the stocks exploited within the TURF type Itaipu RESEX.

Length-frequency data were collected routinely for fisheries management, as part of exploratory surveys (Asila and Ogari 1988, Piñero et al. 1996) beyond evaluated the status of the respective populations or fishery. Among all the fishing practices under use in Itaipu, the most traditional fishery is the beach seine. Many authors argue that artisanal fisheries are a vital component of small community livelihood, playing a major role in food security, health, and well being. These practices are often the cheapest and most accessible sources of animal protein and micronutrients essential to local communities (Youn et al. 2014, Belton and Thilsted 2014).

Within the Itaipu coastal zone, this beach seine fishery provided subsistence and established the modes of social reproduction of the Itaipu fishers for more than two centuries (Kant de Lima and Pereira 1997). The local traditional ecological knowledge (TEK, sensu Berkes 1999) associated with this fishery provided the legal framework for the establishment of the Itaipu Extractive Reserve (Itaipu RESEX) in 2014. The information on the growth parameters here presented for a set of commercial species exploited by this fishery becomes essential for local management of the resources, meeting the objectives of a TURF like protected area.

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